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(54) **IMAGE CAPTURING APPARATUS, METHOD OF CONTROLLING THE SAME, AND STORAGE MEDIUM**

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(52) **U.S. Cl.**

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(57) **ABSTRACT**

An image capturing apparatus comprises an image sensor and a focus detection unit configured to, based on an image signal obtained by the image sensor while performing a scan operation that causes a focus lens to move along an optical axis of the imaging optical system, calculate a focus evaluation value and detect a position of the focus lens at which the focus evaluation value is a maximum, wherein the focus detection unit, in a case where the imaging optical system includes a reflective optical system in which a part of a light beam is blocked, sets a calculation method of the focus evaluation value or a control method of the focus lens during the scan operation based on information relating to a shape of the reflective optical system.

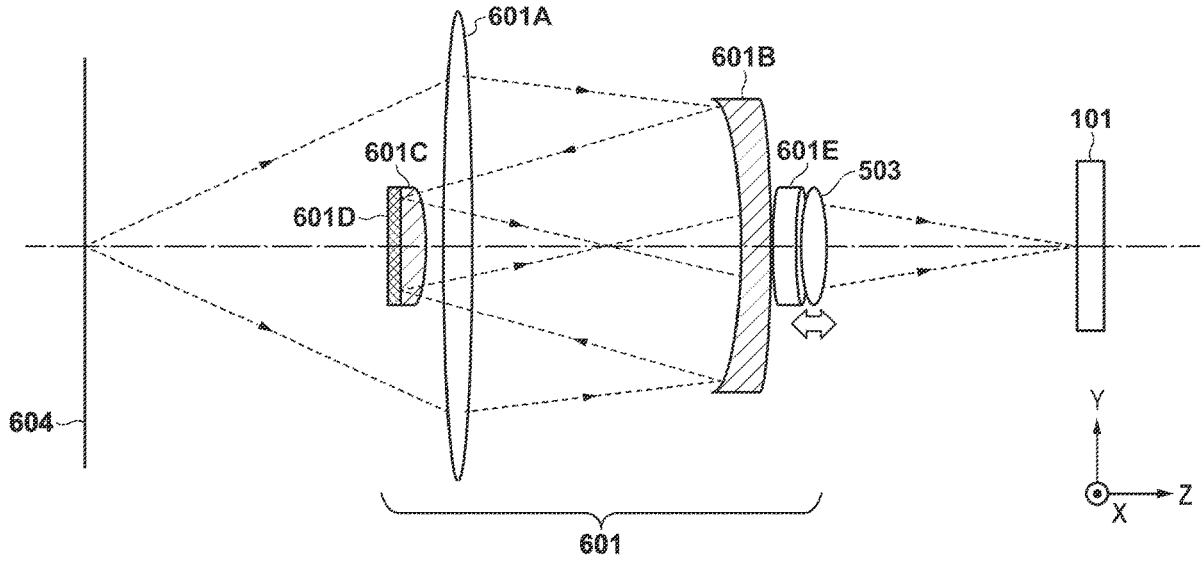

FIG. 1A

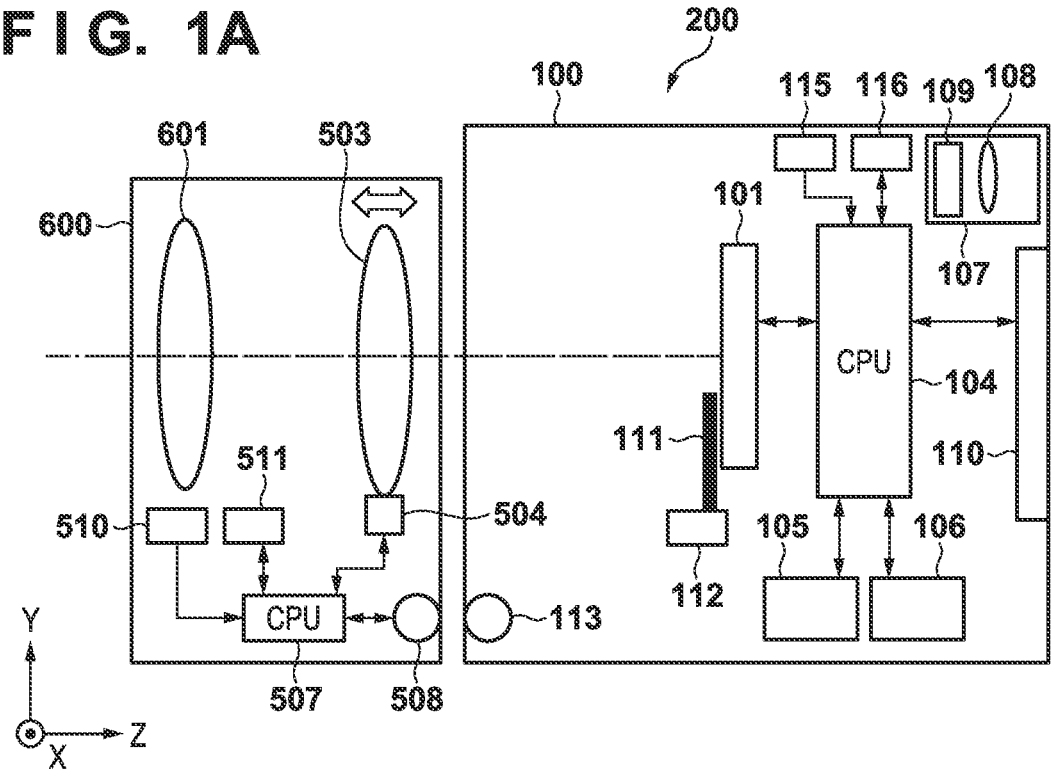
200
100
115
116
109
108
601
503
600
101
107
CPU
104
111
511
110
510
504
105
106
112
CPU
113
Y
507
508
Z
X

FIG. 1B

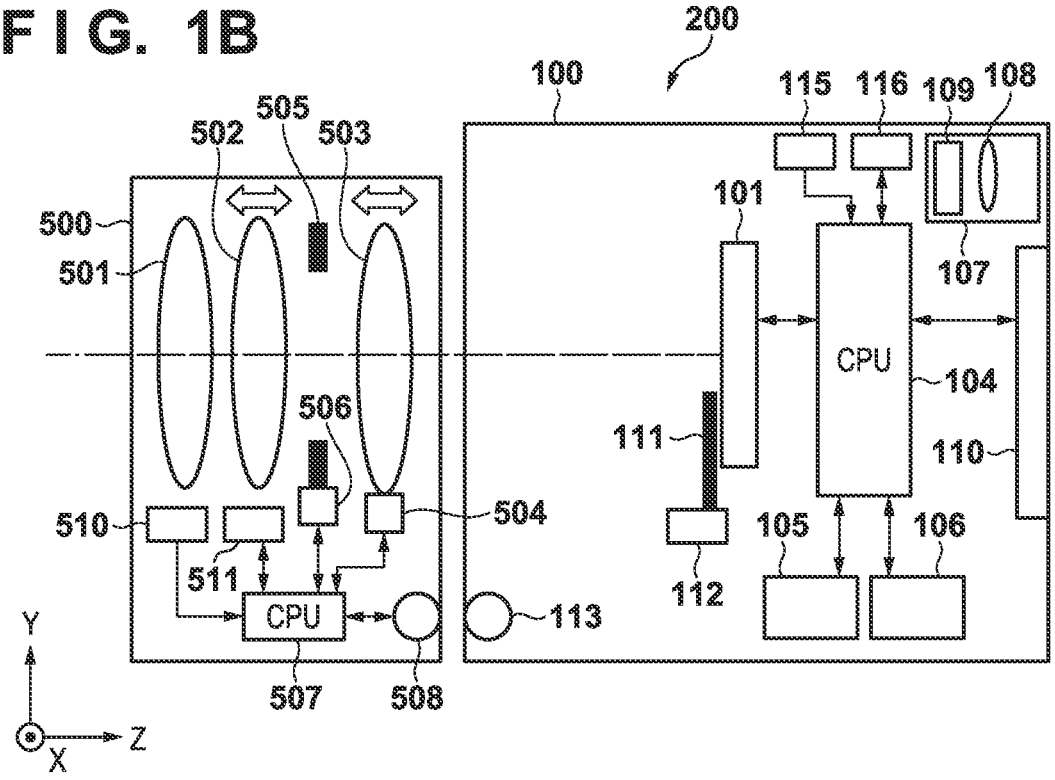
200
100
115
116
109
108
505
502
503
101
500
501
107
CPU
104
506
111
110
510
504
105
106
511
112
CPU
113
Y
507
508
Z
X

FIG. 2

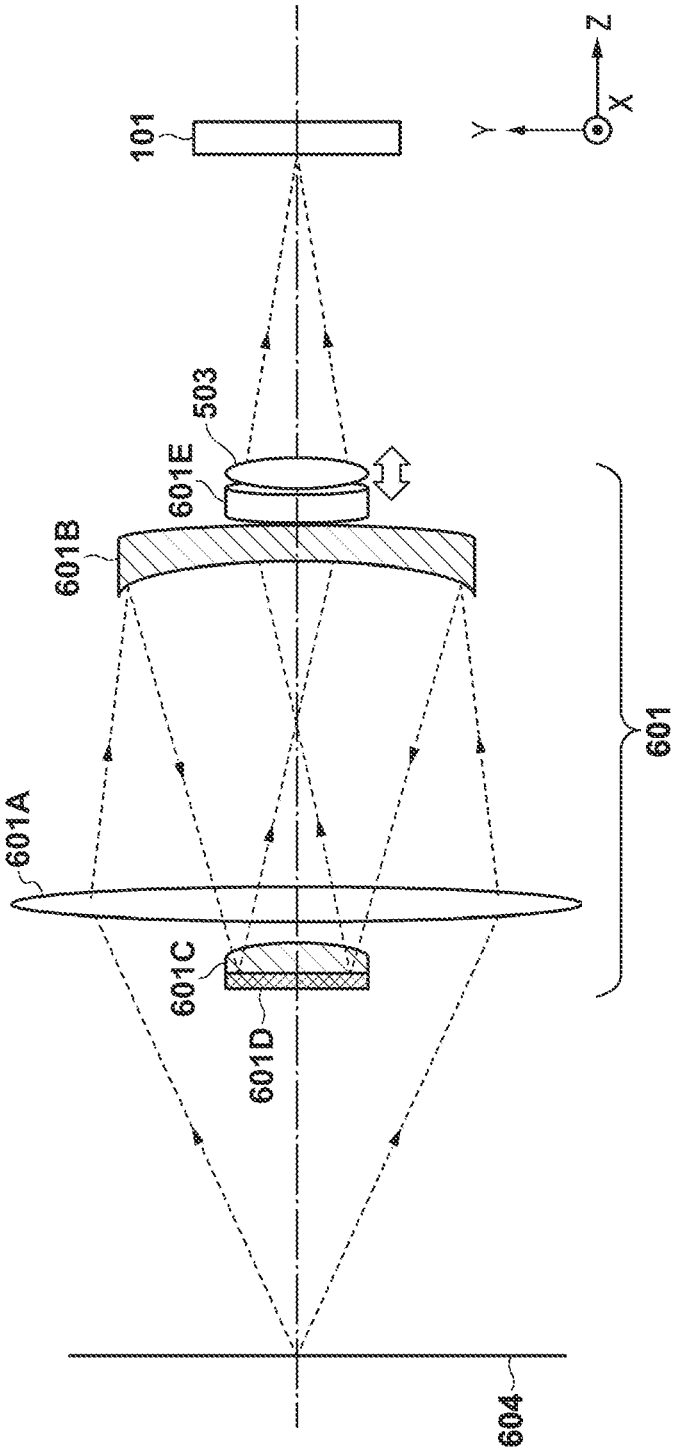

FIG. 3A

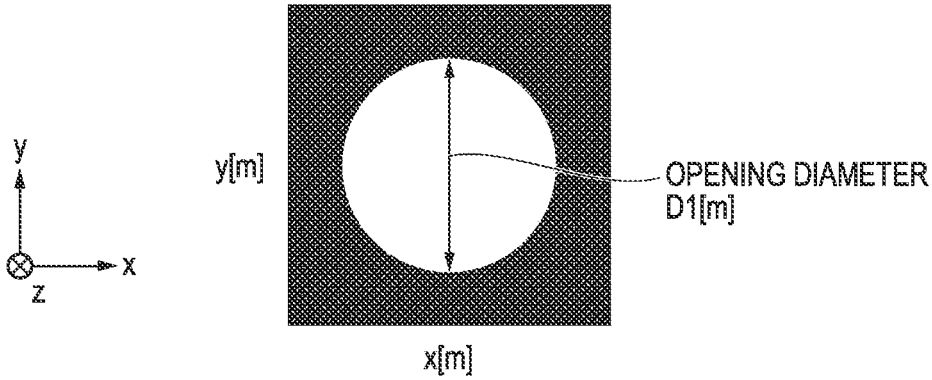

FIG. 3B

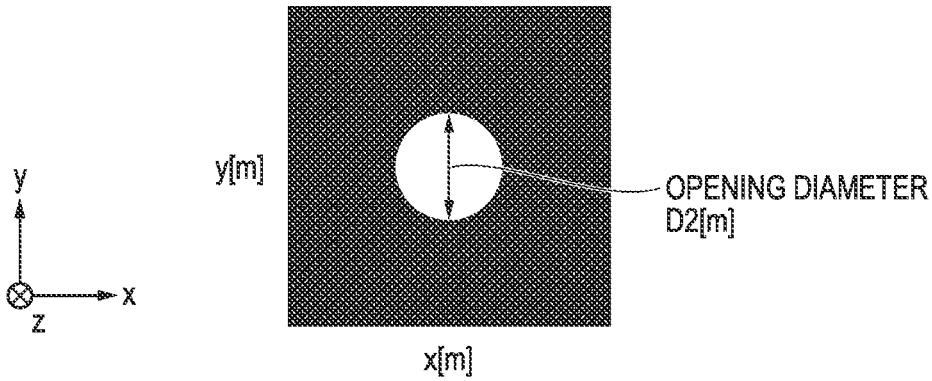

FIG. 3C

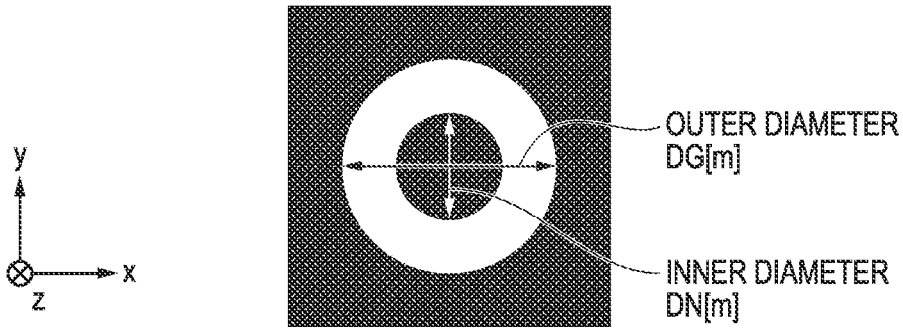

FIG. 4A

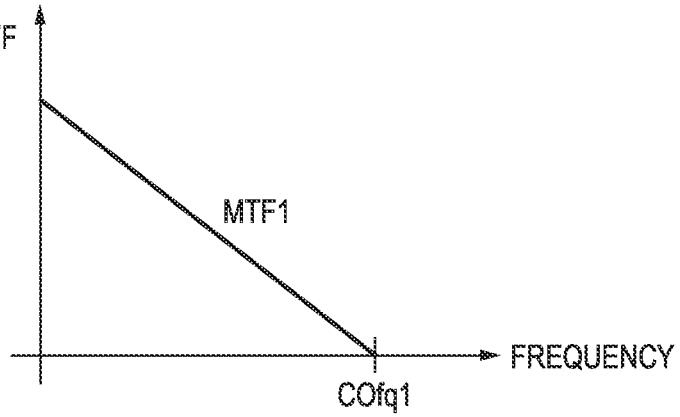

FIG. 4B

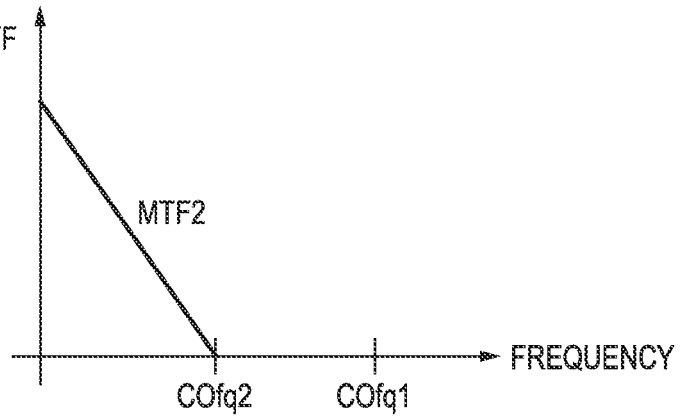

FIG. 4C

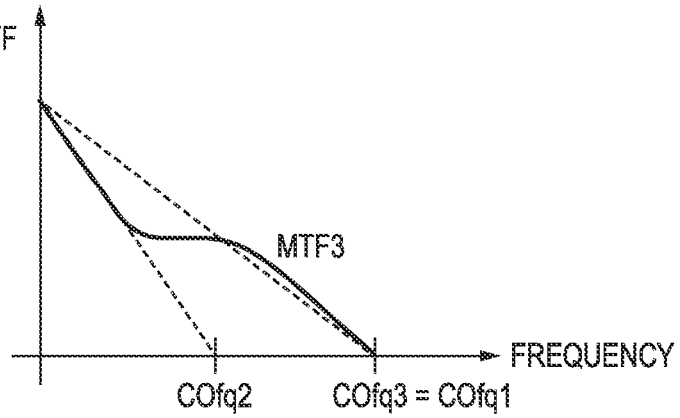

FIG. 5

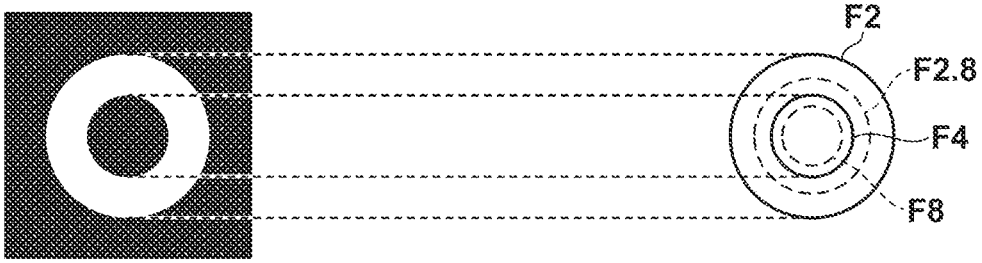

FIG. 6A

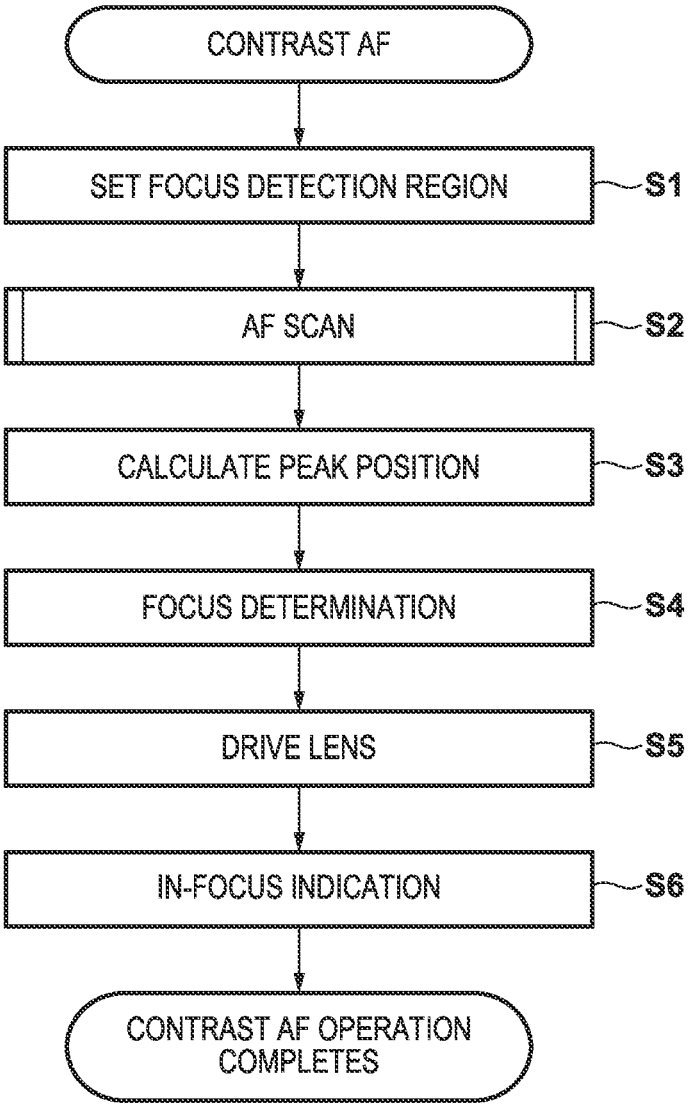
CONTRAST AF
SET FOCUS DETECTION REGION
S1
AF SCAN
S2
CALCULATE PEAK POSITION
S3
FOCUS DETERMINATION
S4
DRIVE LENS
S5
IN-FOCUS INDICATION
S6
CONTRAST AF OPERATION COMPLETES

FIG. 6B

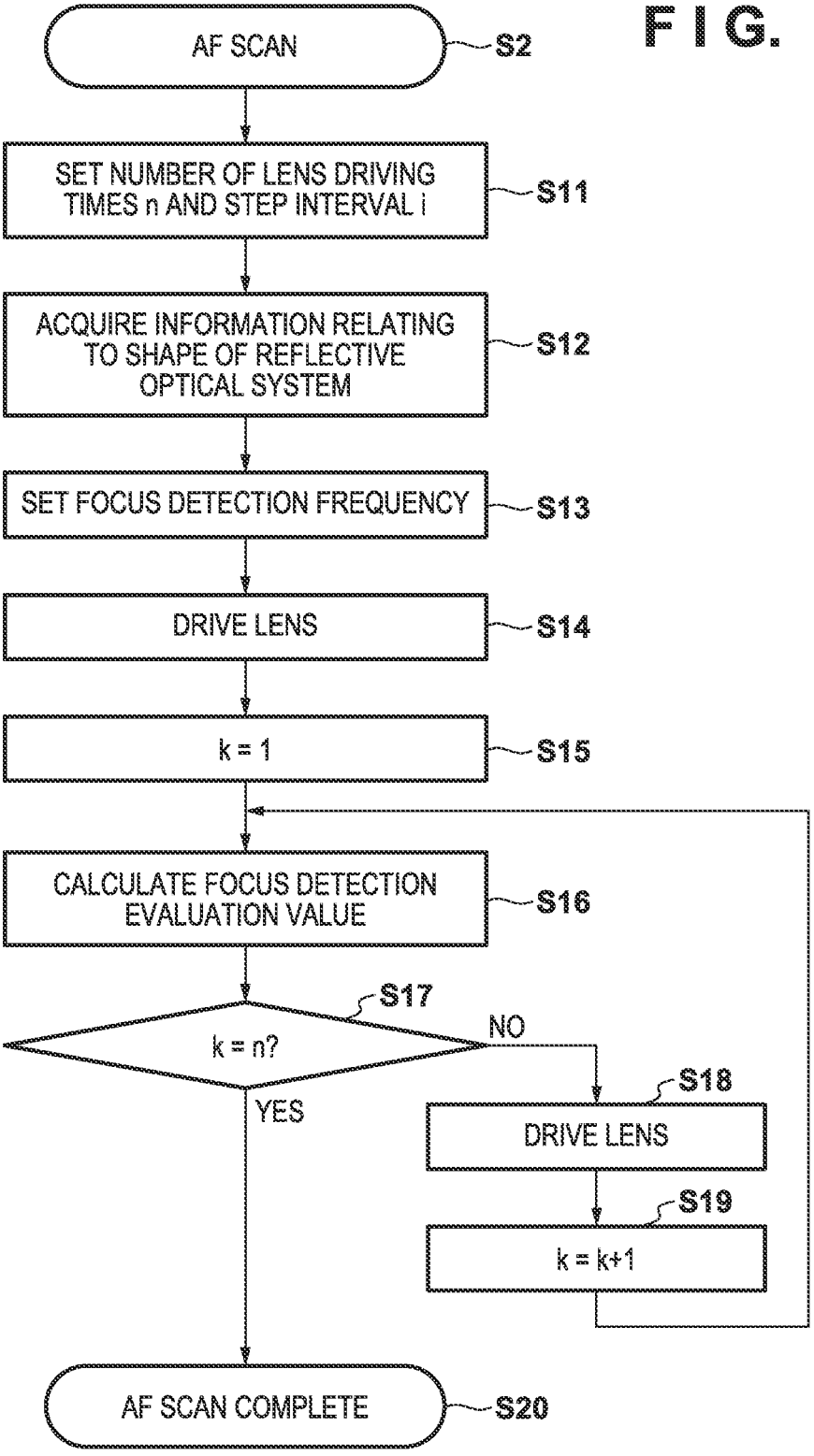
AF SCAN
S2
SET NUMBER OF LENS DRIVING TIMES n AND STEP INTERVAL i
S11
ACQUIRE INFORMATION RELATING TO SHAPE OF REFLECTIVE OPTICAL SYSTEM
S12
SET FOCUS DETECTION FREQUENCY
S13
DRIVE LENS
S14
k = 1
S15
CALCULATE FOCUS DETECTION EVALUATION VALUE
S16
S17
k = n?
NO
YES
S18
DRIVE LENS
S19
k = k+1
AF SCAN COMPLETE
S20

FIG. 7

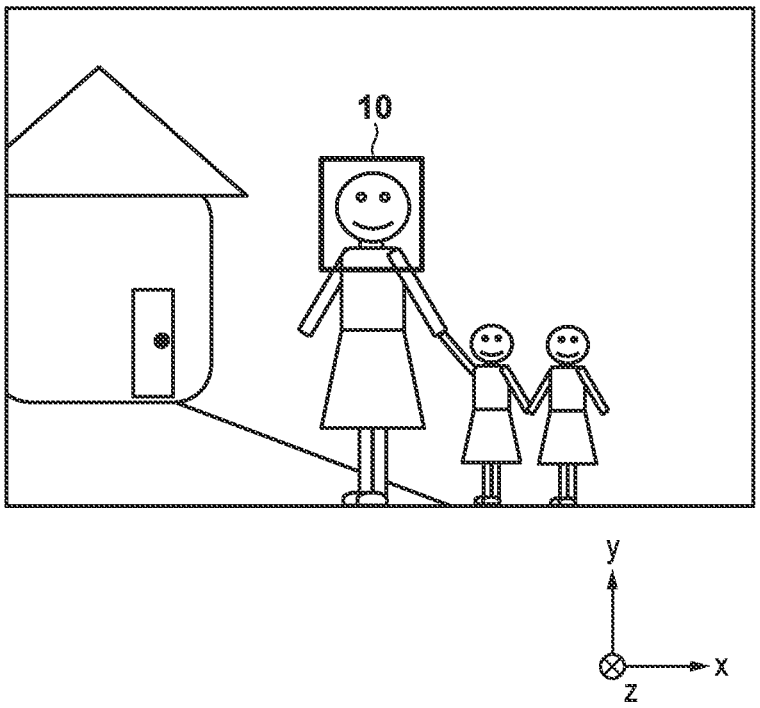

FIG. 8

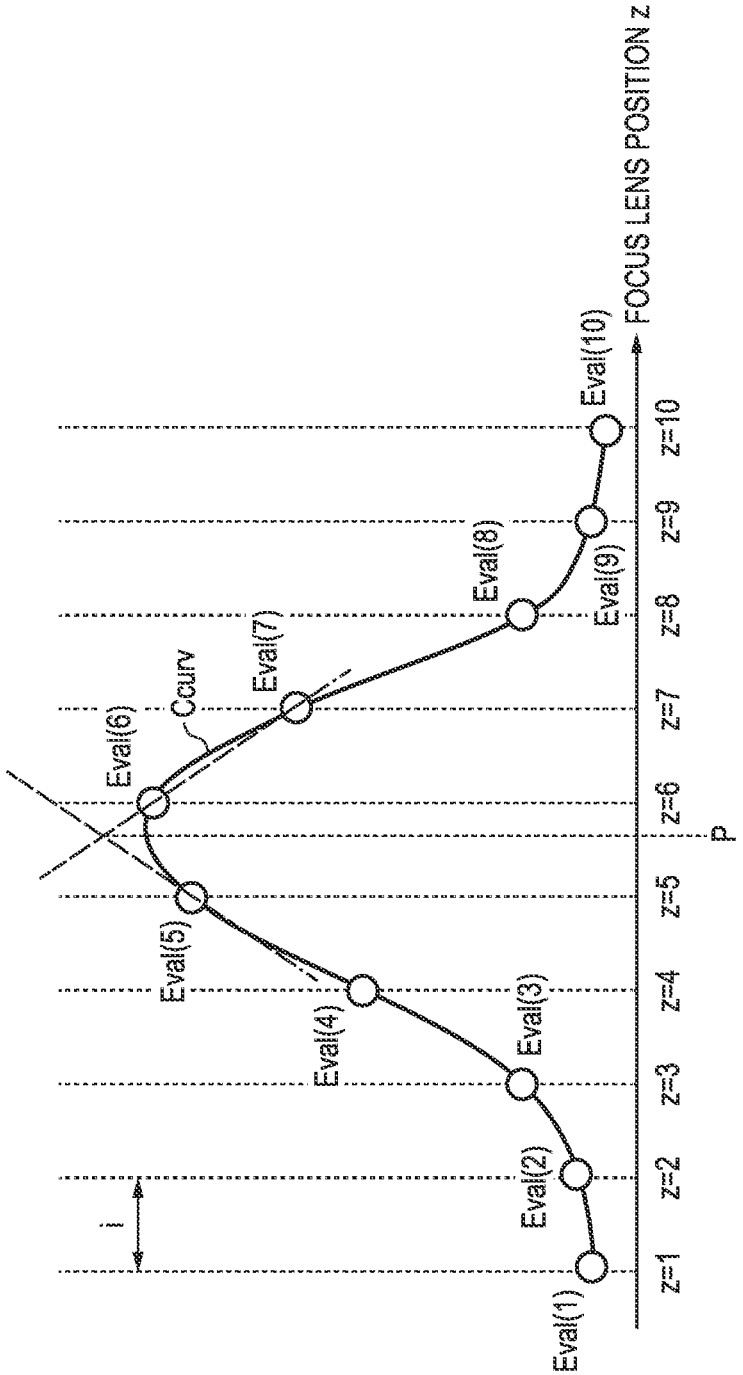
FOCUS LENS POSITION z
z=1
z=2
z=3
z=4
z=5
z=6
z=7
z=8
z=9
z=10
P
i
Eval(1)
Eval(2)
Eval(3)
Eval(4)
Eval(5)
Eval(6)
Ccurv
Eval(7)
Eval(8)
Eval(9)
Eval(10)

FIG. 9

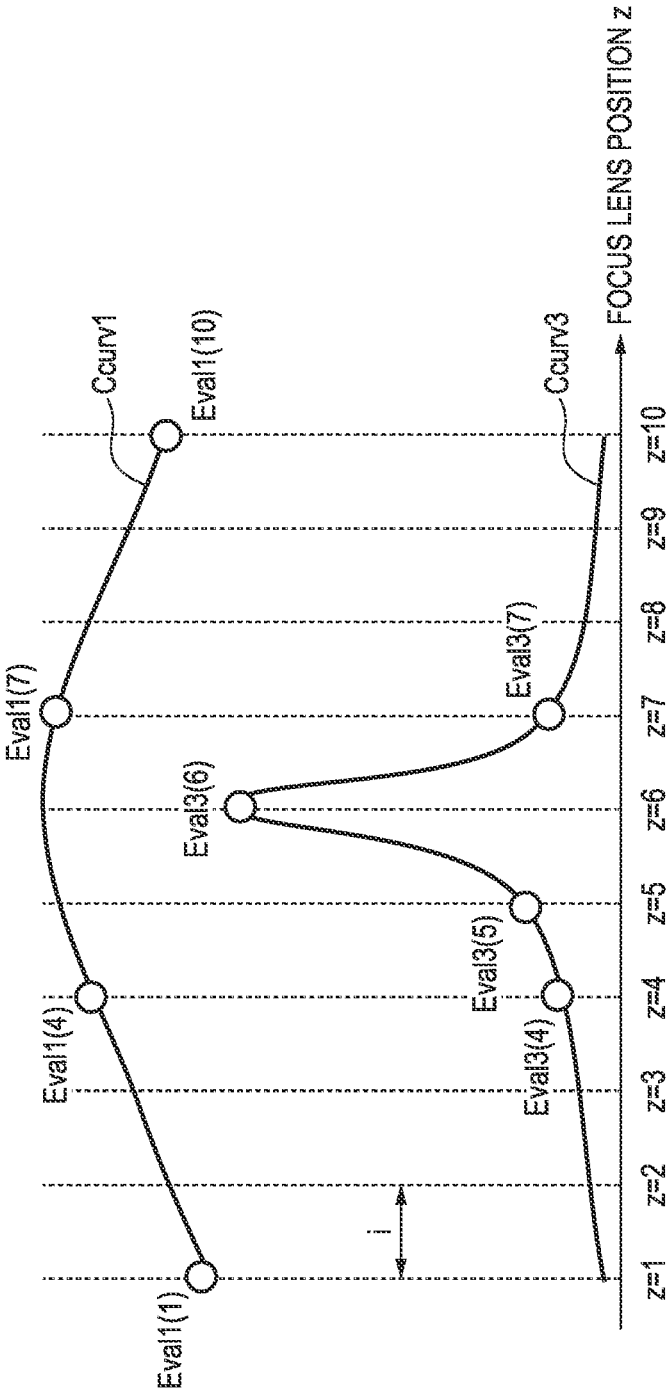
FOCUS LENS POSITION z
z=1
z=2
z=3
z=4
z=5
z=6
z=7
z=8
z=9
z=10
Ccurv1
Ccurv3
Eval1(1)
Eval1(4)
Eval1(7)
Eval1(10)
Eval3(4)
Eval3(5)
Eval3(6)
Eval3(7)
I

FIG. 10

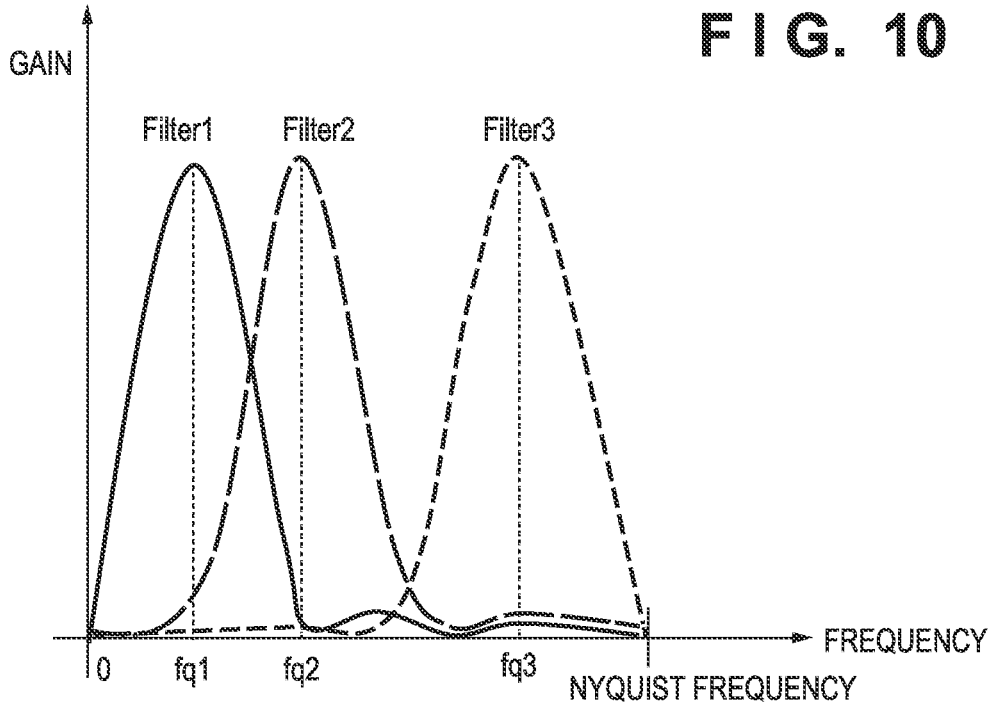
GAIN
Filter1
Filter2
Filter3
FREQUENCY
0
fq1
fq2
fq3
NYQUIST FREQUENCY

FIG. 11

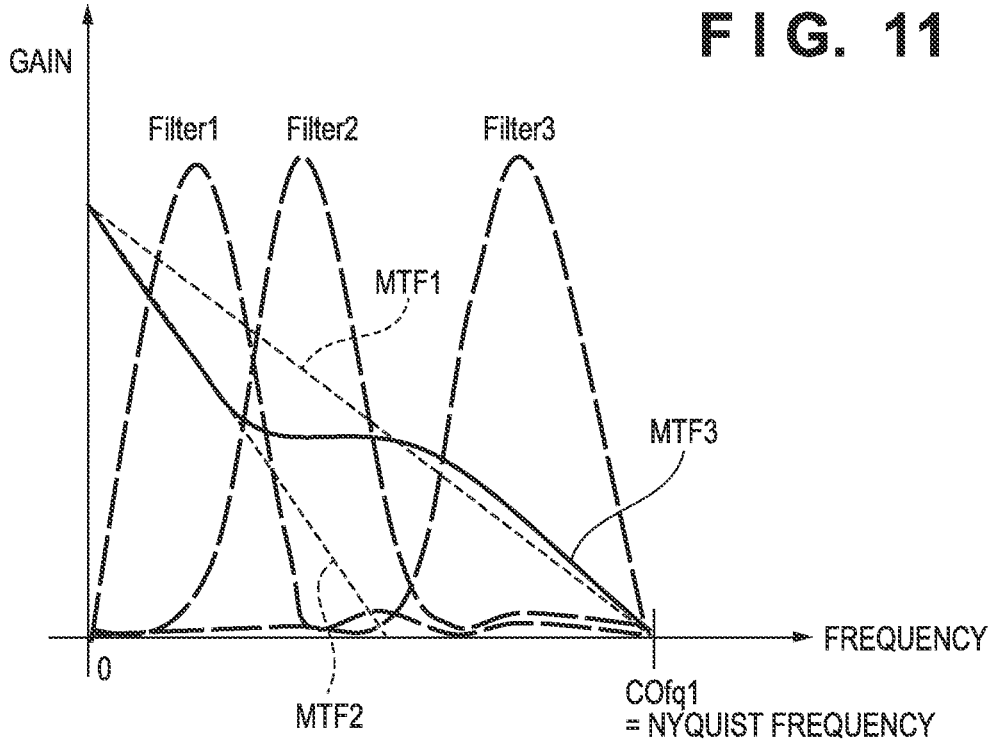
GAIN
Filter1
Filter2
Filter3
MTF1
MTF3
FREQUENCY
0
MTF2
COfq1
= NYQUIST FREQUENCY

FIG. 12

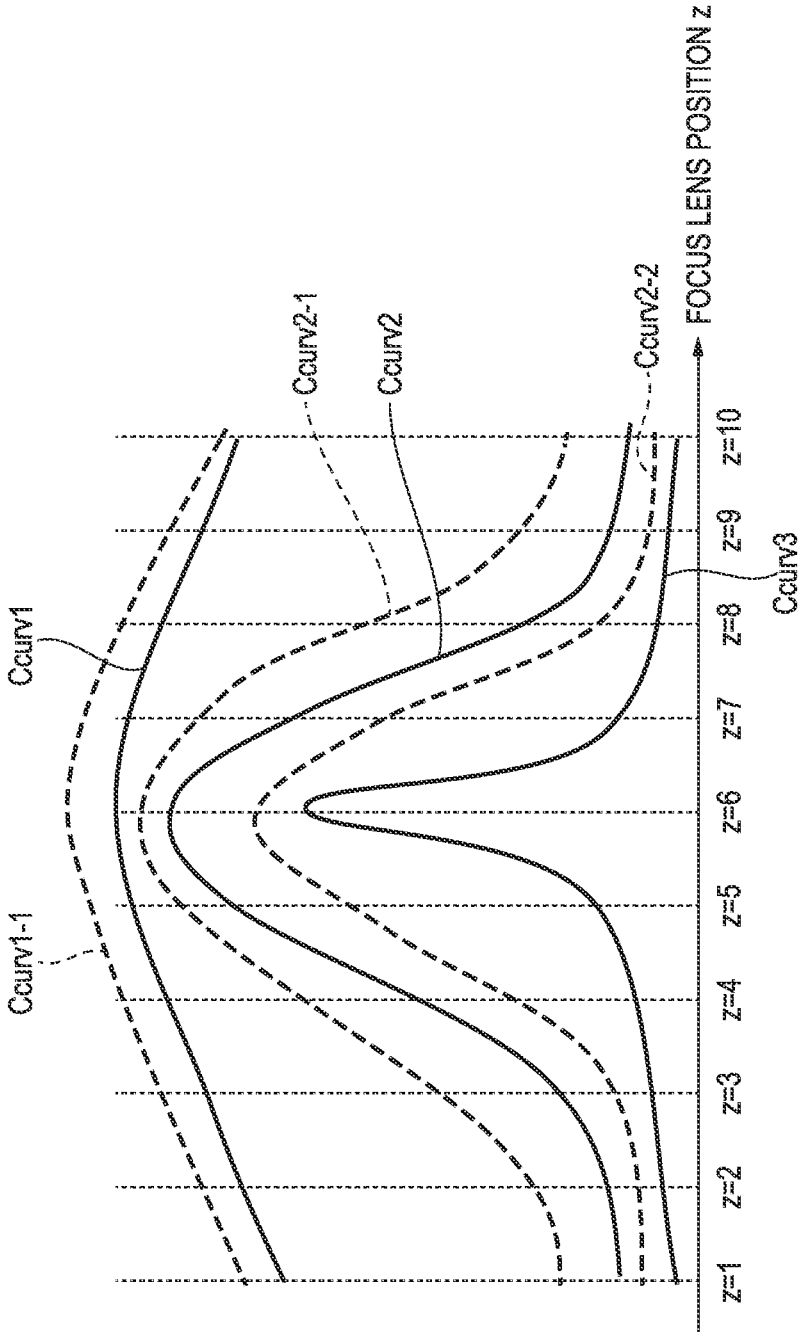
Curv1
Curv1-1
Curv2-1
Curv2
Curv2-2
Curv3
FOCUS LENS POSITION z
z=1
z=2
z=3
z=4
z=5
z=6
z=7
z=8
z=9
z=10

FIG. 13

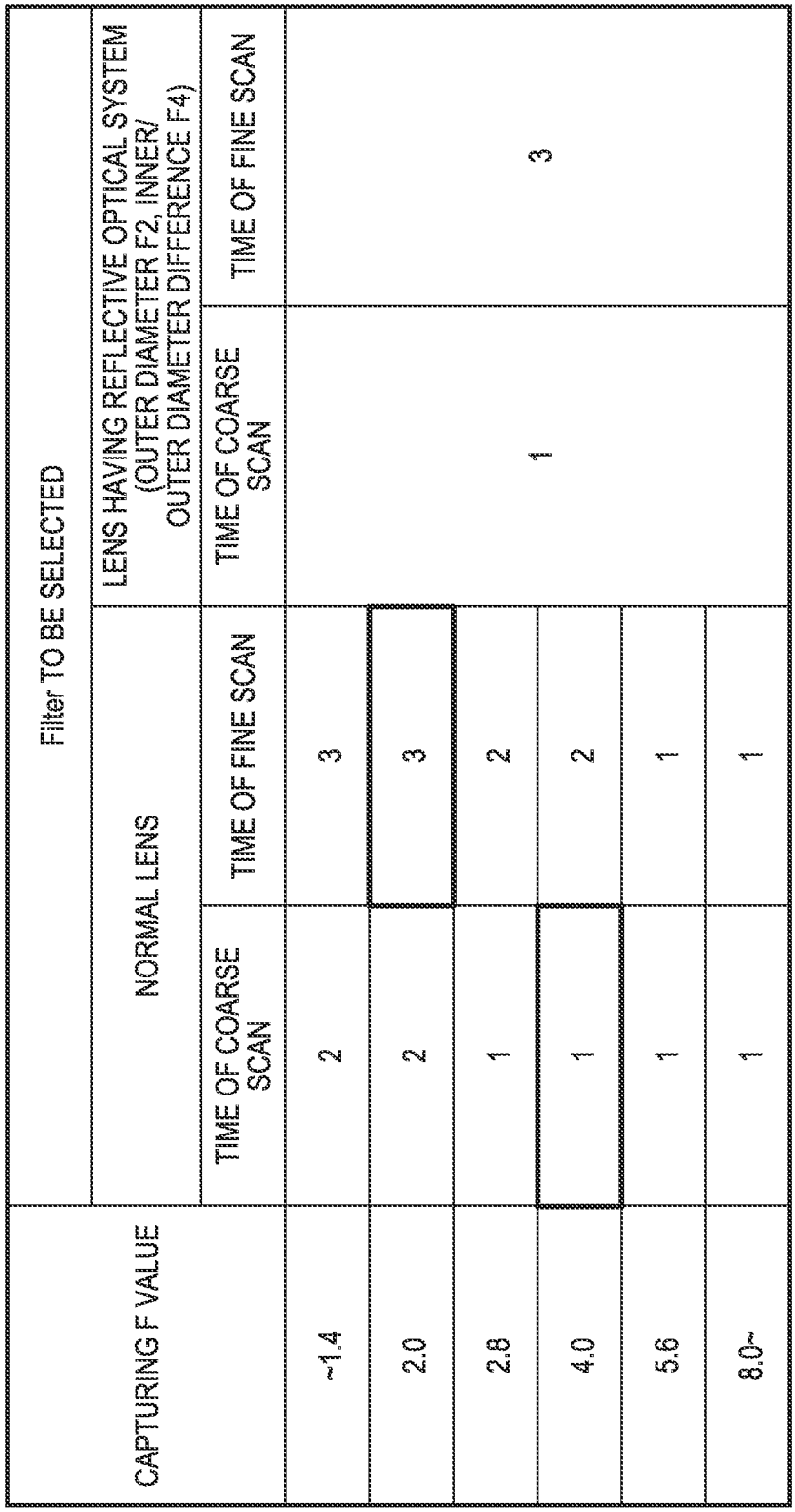
Filter TO BE SELECTED
CAPTURING F VALUE
NORMAL LENS
LENS HAVING REFLECTIVE OPTICAL SYSTEM (OUTER DIAMETER F2, INNER/OUTER DIAMETER DIFFERENCE F4)
TIME OF COARSE SCAN
TIME OF FINE SCAN
TIME OF COARSE SCAN
TIME OF FINE SCAN
~1.4
2
3
1
3
2.0
2
3
2.8
1
2
4.0
1
2
5.6
1
1
8.0~
1
1

FIG. 14

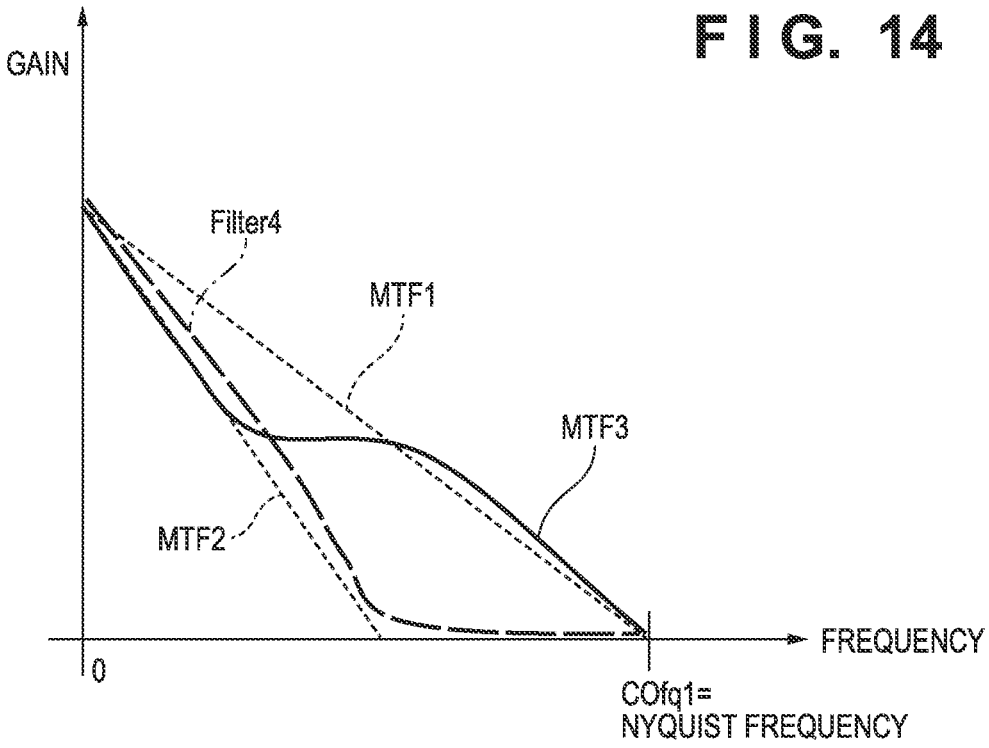
GAIN
Filter4
MTF1
MTF3
MTF2
FREQUENCY
0
COfq1=
NYQUIST FREQUENCY

FIG. 15

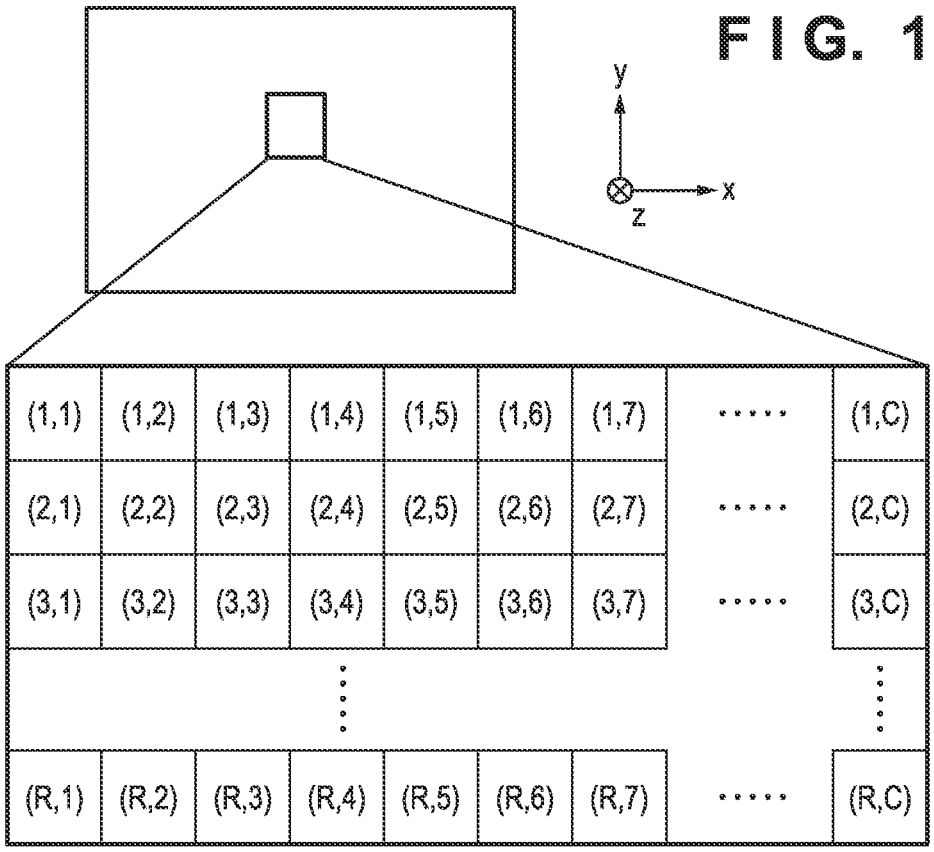
y
x
z
(1,1) (1,2) (1,3) (1,4) (1,5) (1,6) (1,7) ..... (1,C)
(2,1) (2,2) (2,3) (2,4) (2,5) (2,6) (2,7) ..... (2,C)
(3,1) (3,2) (3,3) (3,4) (3,5) (3,6) (3,7) ..... (3,C)
(R,1) (R,2) (R,3) (R,4) (R,5) (R,6) (R,7) ..... (R,C)

IMAGE CAPTURING APPARATUS, METHOD OF CONTROLLING THE SAME, AND STORAGE MEDIUM

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application is a continuation of International Patent Application No. PCT/JP2020/020992 filed on May 27, 2020, which claims priority to and the benefit of Japanese Patent Application No. 2019-105607 filed on Jun. 5, 2019, the entire disclosures of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to a focus adjustment technique in an image capturing apparatus.

Description of the Related Art

[0003] In recent years, an optical system that is a miniaturized imaging lens with a long focal length on the optical axis of which a reflecting mirror is disposed has been proposed (see Japanese Patent Laid-Open No. 2004-85725). In the imaging optical system disclosed in Japanese Patent Laid-Open No. 2004-85725, an imaging lens capable of capturing at a high magnification is realized by internally reflecting light using a reflecting mirror, which enables a long focal length while having a small outer shape.

[0004] However, the image capturing apparatus described in the above patent document has the following problems.

[0005] In an imaging optical system such as that disclosed in Japanese Patent Laid-Open No. 2004-85725, due to the presence of a reflective optical system in which there is internal reflection, change in accordance with a focal position in an MTF (Modulation Transfer Function), which is an absolute value of an optical transfer function (OTF) indicating a resolution of an imaging lens, differs from change in a normal imaging lens. Therefore, with the same focus detection control as that of a normal imaging lens, focus detection accuracy is lower.

SUMMARY OF THE INVENTION

[0006] The present invention has been made in view of the above-mentioned problems, and improves the accuracy of focus detection in an image capturing apparatus that uses an imaging lens having a reflective optical system.

[0007] According to a first aspect of the present invention, there is provided an image capturing apparatus, comprising: an image sensor configured to capture a subject image; and at least one processor or circuit configured to function as a focus detection unit configured to, based on an image signal obtained by photoelectrically converting the subject image in accordance with the image sensor while performing a scan operation that causes a focus lens included in an imaging optical system to move along an optical axis of the imaging optical system, calculate a focus evaluation value indicating a degree of focus of a subject and detect a position of the focus lens at which the focus evaluation value is a maximum, wherein the focus detection unit, in a case where the imaging optical system includes a reflective optical system in which a part of a light beam is blocked, sets a calculation method of the focus evaluation value or a control method of the focus lens during the scan operation based on information relating to a shape of the reflective optical system.

[0008] According to a second aspect of the present invention, there is provided a method of controlling an image capturing apparatus having an image sensor configured to capture a subject image, the method comprising: based on an image signal obtained by photoelectrically converting the subject image in accordance with the image sensor while performing a scan operation that causes a focus lens included in an imaging optical system to move along an optical axis of the imaging optical system, calculating a focus evaluation value indicating a degree of focus of a subject and detecting a position of the focus lens at which the focus evaluation value is a maximum, wherein in the detecting, in a case where the imaging optical system includes a reflective optical system in which a part of a light beam is blocked, a calculation method of the focus evaluation value or a control method of the focus lens during the scan operation is set based on information relating to a shape of the reflective optical system.

[0009] Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIGS. **1**A and **1**B are diagrams showing a configuration of an interchangeable lens type digital camera system which is an embodiment of an image capturing apparatus of the present invention.

[0011] FIG. **2** is a configuration diagram of a reflective optical system.

[0012] FIGS. **3**A to **3**C are diagrams for describing a pupil function.

[0013] FIGS. **4**A to **4**C are diagrams for describing MTFs.

[0014] FIG. **5** is a diagram for describing the correspondence between a diameter and an F value of a reflective optical system.

[0015] FIGS. **6**A and **6**B are flowcharts for describing a focus detection operation.

[0016] FIG. **7** is a view for describing a focus detection region.

[0017] FIG. **8** is a view for describing a focus detection evaluation value.

[0018] FIG. **9** is a diagram for describing a change in a focus detection evaluation value in accordance with a focus detection band.

[0019] FIG. **10** is a diagram for describing a frequency band of a digital filter.

[0020] FIG. **11** is a diagram for describing correspondence between an MTF and a digital filter.

[0021] FIG. **12** is a diagram for describing a focus detection evaluation value at various MTF and focus detection bands.

[0022] FIG. **13** is a diagram for describing focus detection frequency settings.

[0023] FIG. **14** is a diagram for describing a relationship between MTF and digital filter bands.

[0024] FIG. **15** is a diagram for describing a pixel signal for a focus detection region.

DESCRIPTION OF THE EMBODIMENTS

[0025] Hereinafter, embodiments will be described in detail with reference to the attached drawings. Note, the following embodiments are not intended to limit the scope of the claimed invention. Multiple features are described in the embodiments, but limitation is not made an invention that requires all such features, and multiple such features may be combined as appropriate. Furthermore, in the attached drawings, the same reference numerals are given to the same or similar configurations, and redundant description thereof is omitted.

Configuration of Image Capturing Apparatus

[0026] FIGS. **1**A and **1**B are diagrams showing a configuration of an interchangeable lens type digital camera system **200** which is an embodiment of an image capturing apparatus of the present invention. The digital camera system **200** is configured by having a camera body **100**, and an imaging lens **500** or an imaging lens **600**, for example, which are mounted on the camera body **100** in an interchangeable manner. FIG. **1**A shows a state in which the imaging lens **600** which has a reflective optical system is mounted on the camera body **100**, and FIG. **1**B shows a state in which the imaging lens **500** which is normal (does not have a reflective optical system) is mounted on the camera body **100**.

[0027] The imaging lens **500** and the imaging lens **600** are different types of lenses that are mounted interchangeably with respect to the camera body **100**. A light beam transmitted through each lens group in the imaging lens **500** (or **600**) is guided to the image sensor **101** that receives the subject image and performs photoelectric conversion. The image sensor **101** is configured by including pixel portions arranged in a matrix for converting a subject image into an electric signal. A pixel signal obtained by converting a subject image into an electric signal by the image sensor **101** is, in the camera CPU **104**, subjected to various correction processes for obtaining an image signal and a focus detection signal, processes for converting the pixel signal into a live view image, a recorded image, or an EVF image, and the like. In the present embodiment, these processes and the like are performed by the camera CPU **104**, but configuration may be taken such that a dedicated circuit is provided, and these processes are performed by this circuit.

[0028] An operation member **105** is various members for setting an imaging mode and image capturing conditions of the camera (such as the F value, ISO sensitivity, and exposure time). A storage medium **106** is a flash memory, and is a medium for recording a captured still image or a moving image. An in-viewfinder display **107** is configured by being provided with a small and high-definition display **109** such as an organic EL display or a liquid crystal display, and an eyepiece **108**. An external display **110** is configured by an organic EL display or a liquid crystal display having a screen size suitable for being viewed with the naked eye. Various types of information such as the setting state of the camera body **100**, the live view image, and the captured image are displayed on the in-viewfinder display **107** and the external display **110**.

[0029] A focal plane shutter **111** is disposed on a front surface of the image sensor **101**. A shutter driving unit **112** is, for example, a motor, and controls an exposure time for a time of capturing a still image by driving and controlling blades of the shutter. A camera-side communication terminal **113** is provided in a camera mount part for mounting the imaging lens **500** (or **600**). The camera-side communication terminal **113** and a lens-side communication terminal **508** provided in the lens mount part are connected to each other, thereby enabling communication between the camera CPU **104** and a later-described lens CPU **507**.

[0030] The camera CPU **104** is connected to a nonvolatile memory **115** comprising a ROM or the like and a volatile memory **116** comprising a RAM or the like. The camera CPU **104** deploys a program stored in the nonvolatile memory **115** into the volatile memory **116** and executes the program to thereby control the entire digital camera system **200**. The nonvolatile memory **115** also stores various types of information for operations other than programs, information on characteristics of a plurality of types of imaging lenses, and the like.

[0031] The imaging lens **500** (or **600**) is detachable in relation to the camera body **100**, and in FIG. **1**A, the imaging lens **600** which has a reflective optical system is shown, and in FIG. **1**B, the imaging lens **500** which is a zoom lens having a variable focal length is shown. The type of the lens mounted on the camera body **100** is not relevant.

[0032] A light beam from a subject passes through the first lens group **501** or **601**, the second lens group **502** (only in FIG. **1**B), and the third lens group **503**, and is formed as a subject image on the image capturing surface of the image sensor **101** in the camera body **100**. The first lens group **601** is a lens group having a reflective optical system which is a characteristic of the present embodiment. A detailed configuration will be described later.

[0033] The second lens group **502** functions as a variator (variable magnification lens) for performing magnification variation by advancing and retracting in the optical axis direction. The third lens group **503** functions as a focus lens for performing focus adjustment by advancing and retracting in the optical axis direction. The third lens group **503** is driven by a focus driving unit **504** which uses a stepping motor or the like.

[0034] The aperture **505** existing only in FIG. **1**B is configured by a plurality of aperture blades for adjusting the amount of light entering the imaging lens. An aperture driving unit **506** narrows and drives the aperture blades until a predetermined capturing F value is obtained. In the reflective optical system of FIG. **1**A, since it is difficult to install an aperture mechanism composed of an aperture and an aperture driving unit, an aperture mechanism is not present, and in principle usage is performed only with an open F value. The lens CPU **507** communicates with the camera CPU **104** via the lens-side communication terminal **508** and the camera-side communication terminal **113**, transmits and receives various kinds of information, and drives and controls the focus driving unit **504** and the aperture driving unit **506** based on commands from the camera CPU **104**.

[0035] The lens CPU **507** is connected to a nonvolatile memory **510** comprising a ROM or the like and a volatile memory **511** comprising a RAM or the like. The lens CPU **507** deploys a program stored in the nonvolatile memory **510** into the volatile memory **511** and executes the program to thereby control the entire imaging lens **500** (or **600**). The nonvolatile memory **510** also stores, for example, identification numbers and optical information unique to the imaging lens other than the program.

[0036] Although a zoom range and the open F value of the imaging lens **500** are designed according to the intention of

capturing, the imaging lens **600** which has a reflective optical system basically does not have a zoom lens or an imaging aperture control mechanism.

[0037] Next, the reflective optical system in the first lens group **601** shown in FIG. **1**A will be described with reference to FIG. **2**. In FIG. **2**, a left solid line indicates a subject **604**, and dashed lines indicate light rays emitted from one point of the subject **604**. Light emitted from the subject **604** is condensed through the lens **601**A and reflected by the lens **601**B. Further, light reflected and refracted by the lens **601**C passes through the lens **601**B, passes through the lens **601**E, passes through the previously-described focus lens **503**, and is then formed on the image capturing surface of the image sensor **101**. The lens **601**B is a reflective lens that reflects and causes light to go backward in the optical path in FIG. **2**. A light blocking portion **601**D is attached to the lens **601**C on a surface (the surface on the subject side) opposite to the optical path. In this manner, by folding the optical path within the lens, a lens having a long focal length while having a small outer shape can be realized.

[0038] FIGS. **3**A to **3**C are diagrams for describing a pupil function showing the performance of the lens of the imaging optical system in the present embodiment. The pupil function is the light intensity distribution for an aperture surface at an exit pupil distance of the lens. The black portion in the figure shows a state in which light is blocked at an aperture ratio of 0%, and the white portion in the figure shows an aperture state at an aperture ratio of 100%. Assuming an ideal state in which there are no aberrations in the imaging lens and the aperture shape is an ideal circular shape, the aperture pupil shape (white part in FIG. **3**A) becomes a perfect circular shape as shown in FIG. **3**A.

[0039] Considering correspondence with a capturing F value, in a state where the F value is small (close to an open F value), the opening diameter D**1** of the pupil function is large as shown in FIG. **3**A, and where the F value is large (narrow state), the opening diameter D**2** of the pupil function is small as shown in FIG. **3**B. An exit pupil distance z is a lens-specific value, and when the capturing F value is decided, the magnitude of the diameter D of the opening on the exit pupil plane is uniquely decided. The aperture shape for the pupil function of the imaging lens **600** in the present embodiment is a donut shape as shown in FIG. **3**C even in a state where there is no aberration because the light ray is blocked by the light blocking portion **601**D. An outer side diameter and an inner side diameter in the donut-shaped opening of the pupil functions in FIG. **3**C are denoted by outer diameter DG and inner diameter DN, respectively. The magnitudes of the outer diameter DG and the inner diameter DN are also values that are uniquely decided when the exit pupil distance of the imaging lens, the capturing F value, and the diameter of the light blocking portion **601**D are decided.

[0040] In this case, an MTF indicating the resolution of the imaging lens is represented by an absolute value of an OTF which is an autocorrelation of the pupil function. MTF characteristic diagrams respectively corresponding to the pupil functions in FIGS. **3**A to **3**C are shown in FIG. **4**A to FIG. **4**C. For aperture shapes such as shown in FIGS. **3**A and **3**B, which are generally circular pupil functions, the larger the opening diameter D, the higher the values of the MTFs, which are the vertical axes of FIGS. **4**A to **4**C. Large values on the vertical axis are synonymous with high resolution of the lens. Since the horizontal axis is frequency, a significant difference occurs in resolution in the high-frequency band between FIG. **4**A and FIG. **4**B. The frequency at which the MTFs fall to 0 (the resolution limit of the lens) is referred to as the cutoff frequency, and is indicated by COfq**1** and COfq**2** in FIG. **4**A and FIG. **4**B respectively. The cutoff frequency also differs depending on the size D of the opening, and is obtained by $COfq=D/2\lambda f$ (λ: wavelength of light, f: focal length of imaging optical system).

[0041] In the case where the pupil function has an ideal circular shape, the cutoff frequency is obtained by the above equation, but in an actual imaging optical system, the imaging aperture is often different from the circular shape, and also differs in accordance with image capturing conditions (aberration, coordinates x, y on the image capturing surface, and the like), and the MTF changes in a complicated manner. In addition, a donut-shaped pupil function of a lens having the reflective optical system in the present embodiment as in FIG. **3**C exhibits an MTF characteristic diagram MTF**3** as in FIG. **4**C. The cutoff frequency COfq**3** in FIG. **4**C is equal to COfq**1** when the outer diameter DG=D**1**. In other words, the cutoff frequency is a value decided by the magnitude of the outer diameter DG. In the low frequency region, as can be seen from an autocorrelation relation between the pupil function and the MTF, MTF**3** approaches an MTF for an opening whose diameter is the difference between the outer diameter and the inner diameter (hereinafter referred to as the inner/outer diameter difference). That is, in FIG. **3**C, when DG−DN=D**2**, MTF**3** shown in FIG. **4**C shows values close to MTF**2** shown in FIG. **4**B in the low frequency region (<COfq**2**). As described above, in the optical system of the present embodiment, although the pupil function has a special shape, since the magnitudes DG and DN of the outer diameter and the inner diameter on the exit pupil plane are values which are decided in accordance with design from the diameter and the open F value of the light blocking portion **601**D shown in FIG. **2**, the MTF, which is the lens performance, can also be predicted as in FIG. **4**C.

[0042] If the imaging lens **600** and the camera body **100** are an integrated camera, an MTF which is calculated in advance may be held. On the other hand, in the interchangeable lens system, the imaging lens **600** holds in the nonvolatile memory **510** values of parameters appropriately selected from the magnitude DN of the inner diameter, the magnitude DG of the outer diameter, the pupil function P, the lens exit pupil distance LPO, the lens MTF, and the like. Then, information on the shape of the reflective optical system of the lens is communicated to the camera body **100** via lens-side communication terminal **508** and the camera-side communication terminal **113**. Further, as shown in FIG. **5**, information of the F value corresponding to the diameter may be communicated as a value instead of the magnitude DN of the inner diameter and the magnitude DG of the outer diameter. For example, information may be communicated by setting the magnitude of the outer diameter DG=F**2** and the inner/outer diameter difference=F**4**. In addition, configuration may be taken such that some information in the interchangeable lens system is held in the nonvolatile memory **115** on the camera side, and only some information is communicated from the lens.

[0043] Next, the focus detection operation in the present embodiment will be described with reference to FIGS. **6**A to **6**C. In the present embodiment, the focus detection operation is generally performed by a technique called contrast AF (autofocus).

[0044] First, in step S**1** of FIG. **6**A, a focus detection region is set. For example, when a captured image as shown in FIG. **7** is obtained by the camera CPU **104**, a face in the vicinity of a screen center portion is detected as a main subject, and a focus detection region **10** is set. The size and position coordinates (x, y) of the focus detection region **10** may be arbitrarily set by a photographer, or may be automatically set by a face detection function or the like when a face is included in a captured image as shown in FIG. **7**.

[0045] Next, in step S**2**, an AF scan operation is performed. In the AF scan operation, while the focus lens **503** is caused to move along the optical axis, a focus detection evaluation value indicating a degree of focus is calculated with a number of lens driving times n and a step interval i that are set in step S**11**. Here, the AF scan operation performed in step S**2** will be described in detail with reference to the flowchart of FIG. **6**B.

[0046] First, when the AF scan operation is started, the number of lens driving times n and the step interval i are set in step S**11**. In contrast AF, the focus evaluation value is acquired while the focus lens is caused to move in the optical axis direction, and the focus lens **503** is caused to stop when the focus evaluation value reaches a local maximum (contrast of the subject is a maximum), to thereby acquire an image that is in focus. Therefore, the number of times of driving n and the step interval i of the focus lens should be set within a range in which the local maximum value of the contrast can be obtained.

[0047] For example, assume that, when the focus lens position z is caused to change as indicated by the horizontal axis in FIG. **8**, the contrast curve Ccurv is acquired as with Ccurv in FIG. **8**, and the focus evaluation values Eval(n) at the respective focus lens positions are obtained. In this case, the number of lens driving times and the step interval set in step S**11** may be set with the number of lens driving times n=10 and the step interval=i, or the detection may be stopped with n=7 because it was possible to detect a local maximum value when the number of lens driving times n=7. A method such as the following is a well-known technique. First, as shown in FIG. **9**, the local maximum position of an approximate focus evaluation value is found by first coarsely scanning with the number of lens driving times n=4 and a step interval 3i (between Eval**1**(**4**) and Eval**1**(**7**) on Ccurv**1** in FIG. **9**). Then, in order to detect the focal position with higher accuracy, the vicinity of the local maximum value is finely scanned with a step interval i (from Eval**3**(**4**) to Eval**3**(**7**) on Ccurv**3** in FIG. **9**), thereby obtaining a focal position equivalent to that in FIG. **8**. These operations are hereinafter referred to as a coarse scan (coarse scan operation) and a fine scan (fine scan operation). In this instance, in FIG. **9**, the number of lens driving times in the coarse scan is 4, the step interval is 3i, the number of lens driving times in the fine scan is 4, and the step interval is i. A method of calculating each focus evaluation value and a method of setting an appropriate contrast curve will be described later.

[0048] Next, in step S**12**, the camera CPU **104** acquires information on the shape of the reflective optical system according to the image capturing condition (zooming, focusing, F value, and image height) from the nonvolatile memory **510** of the imaging lens **600** or the nonvolatile memory **115** of the camera body **100**. As described above, the content of the information is appropriately selected from the magnitude DN of the inner diameter, the magnitude DG of the outer diameter, the pupil function P, a lens exit pupil distance LPO, the lens MTF, information of the F value corresponding to the diameter, and the like. The camera CPU **104** acquires these pieces of information from the aforementioned nonvolatile memories **510** or **115**, by communication with the imaging lens **600**, or by communication within the camera body **100**.

[0049] Next, in step S**13**, a focus detection frequency is set. Here, a focus detection frequency band of a digital filter is set. FIG. **10** is a diagram showing an example of the frequency band of the digital filter. The Nyquist frequency shown here is a value determined by the pixel pitch of the image sensor **101**, and for example, if the pixel pitch of the image sensor **101** is 4 microns, the Nyquist frequency can be obtained as 1/(0.004×2)=125 (lp/mm: line pairs/millimeter)). This indicates that a subject image finer than 125 (lp/mm) cannot be resolved on the image sensor **101**.

[0050] In FIG. **10**, the horizontal axis represents the frequency, the vertical axis represents the gain, and Filter**1** indicated by the solid line has a center frequency fq**1**. Filter**2**, Filter**3** have higher frequency bands than Filter**1**, and their center frequencies are fq**2** and fq**3**, respectively. In general, it is indicated that the higher the frequency band, the steeper the contrast evaluation value changes. Therefore, if the focus evaluation value obtained when the filter processing having a frequency characteristic such as Filter**1** is performed is the contrast curve Ccurv**1** in FIG. **9**, the focus evaluation value obtained when the filter processing having a frequency characteristic such as Filter**3** is performed becomes a contrast curve Ccurv**3** that is sharper than the contrast curve Ccurv**1**. This is because the lens MTF of a high frequency component has a relatively higher amount of loss than the lens MTF of a low frequency component even with the same amount of blur (amount of driving of the focus lens).

[0051] In contrast AF focus detection, since the focus lens is generally driven when the focus evaluation value Eval reaches a local maximum, the shape of the contrast curve Ccurv also greatly affects the focus detection accuracy. For example, in FIG. **9**, the focus lens position at which the focus evaluation value is a local maximum during the coarse scan is z=7, while the focus lens position at which the focus evaluation value is a local maximum during the fine scan is z=6. During the coarse scan, it is desirable that Ccurv**1** of the contrast curve shows a gradual change because of the wide step interval. This is because, when performing focus detection with a sharp contrast curve Curv**3** at the time of a coarse scan, there is a fear that a local maximum value may be missed due to a wide step interval. Therefore, in the case of a coarse scan, it is desirable that the focus detection frequency set in step S**13** is in a low range. In contrast, in the case of a fine scan, since the step intervals are narrow, the use of a sharp curve such as the contrast curve Ccurv**3** enables detection of a local maximum value of the focus detection evaluation value Eval with high accuracy. Accordingly, it is desirable that the focus detection frequency set in step S**13** is in a high range.

[0052] Further, the contrast curve Ccurv has values decided by multiplying the focus detection frequency by the MTF of the lens. The MTFs of the lens shown in FIGS. **4**A to **4**C and the focus detection frequencies shown in FIG. **10** are considered together. Now, assuming that the Nyquist frequency and the cutoff frequency of the lens are the same, it is possible to consider them together on a graph with the frequency on the horizontal axis and the gain on the vertical

axis as shown in FIG. **11**. In FIG. **11**, the frequencies of Filter**1**, Filter**2**, and Filter**3** are indicated by dashed-dotted lines, MTF**1** and MTF**2** are indicated by dashed lines, and MTF**3** is indicated by a solid line. The MTFs shown here are MTFs of the focus lens position (for example, the focus lens position z=6) for which the focus evaluation value is a local maximum (in-focus state), and respective MTF characteristics are different in a defocus (not in focus) state. However, an MTF gain in the defocus state is lower than the MTF at a time of focus, and the value of the MTF generally gets relatively lower each time the defocus increases. At this time, the contrast evaluation value Eval (z=6) is close to a value proportional to a value resulting from multiplying the gain of the MTF and the gain of Filter.

[0053] That is, as shown in FIG. **12**, the focus evaluation value Eval obtained by applying the digital filter Filter**1** is almost unchanged between MTF**2** and MTF**3**, and is Ccurv**1**. Since the output with MTF**1** is higher than with MTF**2** or MTF**3**, the focus evaluation value is also a large output as with Ccurv**1**-**1**. Similarly, the focus evaluation values Eval obtained by applying the digital filter Filter**2** are respectively different, with Ccurv**2**-**1** for MTF**1**, Ccurv**2** for MTF**2**, and Ccurv**2**-**2** for MTF**3**. The focus evaluation value Eval obtained by applying the digital filter Filter**3** is Ccurv**3** which hardly changes between MTF**1** and MTF**3**, and a focus evaluation value is not obtained with MTF**2** because the gain of the MTF is 0 (not shown).

[0054] Since the MTFs are known values in accordance with the configuration of the imaging optical system, when performing contrast AF, a desired contrast curve Ccurv can be obtained by appropriately setting the focus evaluation band of the digital filter in advance. At this time, in the case of a special imaging optical system such as a lens having the reflective optical system shown in the present embodiment, the focus detection frequency needs to be set in consideration of the fact that the MTF exhibits change such as with the shape of MTF**3**.

[0055] In an interchangeable lens system, in a case where the digital filter selected at a time of a coarse scan and a fine scan by the general imaging lens **500** is set as in the left column of FIG. **13** and if, for example, a capturing F value corresponding to the inner/outer diameter difference and the inner diameter of the imaging lens **600** having the reflective optical system of the present embodiment is communicated, an entry in the table shown by the thick frame of FIG. **13** is referred to. That is, it is sufficient to select the same Filter**1** as for F4.0 corresponding to the inner/outer diameter difference F4 during a coarse scan, and select the same Filter**3** as for F2.0 corresponding to the outer diameter difference F2 during a fine scan. As described above, in step S**13**, the signal processing method for a case of obtaining the focus evaluation value is switched in accordance with the information on the shape of the reflective optical system of the imaging lens **600**. Here, the method of switching the digital filter has been described, but the step interval i may be set in accordance with information on the shape of the reflective optical system of the imaging lens **600**. In addition, when low-pass Filter**4** as shown in FIG. **14** is applied to MTF**3** of the imaging lens **600**, the characteristic becomes the same as that of MTF**2**, and therefore, it can be treated as the same characteristic as that of F4.0 of a normal lens.

[0056] Next, in step S**14**, the focus lens **503** is driven along the optical axis by a movement interval of one step of an AF scan. In step S**15**, a variable k indicating the number of times the focus lens **503** has been driven is set to 1.

[0057] Next, in step S**16**, a focus evaluation value Eval is calculated. Here, the focus evaluation values Eval at the respective focus lens positions z are obtained by performing, for example, a convolution operation of the digital filters shown in step S**13** with respect to the focus detection region set in step S**1**. For example, if Filter**1** set in step S**13** has the filter taps of (TAP1, TAP2, TAP3) and the pixel values gaso(x, y) in the focus detection region are in the array shown in FIG. **15**, a pixel array value f(x, y) after the digital filter calculation can be obtained by:

$$f(x, y)=\mathrm{TAP1}\times gaso(x, y)+\mathrm{TAP2}\times gaso(x+1, y+1)+\mathrm{TAP3}\times gaso(x+2, y+2)$$

[0058] The number of taps (here, 3) (TAP1, TAP2, TAP3) may be set in accordance with the focus detection frequency described above in step S**13**. For example, the focus detection evaluation value Eval is obtained by calculating the largest absolute value among the pixel values of f(x, y) after the filter operation.

[0059] The method of calculating the focus evaluation value described here is an example, and the digital filter may be two-dimensional, and the focus evaluation value for each line may be obtained. Further, the focus evaluation value Eval may be obtained by performing a Fourier transform or the like of the image signal and then applying the digital filter gain of FIG. **10**, and the method is not relevant as long as the focus evaluation value Eval indicating contrast in the image can be indicated. In addition, the band setting of the digital filter may be performed in conjunction with change of the recording frequency, depending on an addition state of the image signal (for a still image, for a live view display, for a moving image, and so on).

[0060] Next, in step S**17**, it is determined whether or not the variable k has reached the number of lens driving times n set in step S**11**. If the variable k has reached the number of lens driving times n, the processing proceeds to step S**20** to end the AF scan operation, and if not, the processing proceeds to step S**18** where the focus lens **503** is driven by one step of the AF scan.

[0061] In step S**19**, the variable k is incremented, and the processing returns to step S**16**. Then, the operations of step S**16** to step S**18** are repeated until the variable k becomes equal to the number of lens driving times n set in step S**11**.

[0062] As described above, when the AF scan is divided into a coarse scan and a fine scan, the operations of step S**13** to step S**19** are performed twice: once for the coarse scan and once for the fine scan.

[0063] Returning to the description of FIG. **6**A, in step S**3**, the peak position calculation is performed from the focus evaluation values Eval obtained in step S**16**. When focus evaluation values Eval as shown in FIG. **8** are obtained, the focus lens position z=6 may be set as the focus evaluation value peak position (in-focus position) with Eval(**6**) which is the local maximum value as the focus evaluation value peak. However, for higher accuracy, a focus lens position P, which is a peak position of the focus evaluation value equivalent to performing an interpolation calculation using the focus evaluation value Eval in the vicinity of the local maximum value of the focus evaluation value, the step intervals, and the focus lens position z is obtained. A method of calculating the interpolation may be by linear interpolation, or a local maximum value may be obtained by high-order approximation from the obtained discrete focus evaluation value Eval.

[0064] In the example of FIG. **8**, an interpolation calculation is performed by linear interpolation using three points in the vicinity of the local maximum value, and it is calculated that there is a local maximum value between the focus lens positions z=5 and z=6, and the focus lens position P is in the vicinity of z=5.7.

[0065] Next, in step S**4**, focus determination (in-focus state determination) of the peak position of each focus detection region is performed, and the process proceeds to step S**5**. Here, the presence or absence of the local maximum value of the AF evaluation value with respect to the focus lens position is determined, and the focus lens position in the case where a local maximum value is present is calculated. Further, the reliability of a change curve of the AF evaluation value in the vicinity of the local maximum value is evaluated. In this reliability evaluation, it is determined whether the obtained AF evaluation value has taken a local maximum value because the optical image of the subject is formed on the image sensor **101** or has taken a local maximum value due to other external disturbance.

[0066] As a detailed method of focus determination, for example, a method as described in FIG. 10 to FIG. 13 of Japanese Patent Laid-Open No. 2010-078810 may be used. That is, whether or not the AF evaluation value indicating the in-focus state is mountain-shaped is determined based on the difference between the largest value and the smallest value of the focus evaluation value, the length of a portion inclined at an inclination equal to or more than a predetermined value (SlopeThr), and the gradient of the inclined portion. By this, it is possible to perform focus determination. If the focus determination is not good, the in-focus indication in step S**6** is displayed as out-of-focus, or the AF scan operation of step S**2** is redone.

[0067] Next, in step S**5**, the focus lens **503** is driven in the optical axis direction to the focus lens position P obtained in step S**3**.

[0068] Finally, in step S**6**, an in-focus indication is made. When the focus determination is OK in step S**4**, an in-focus indication (for example, a green box is displayed) is made in the focus detection region of FIG. **7** to inform a user of the end of the focus detection operation. When the focus determination is OK in step S**4**, an out-of-focus indication (for example, a red box is displayed) is made in the focus detection region of FIG. **7** to inform a user of the end of the focus detection operation. The above operation is performed and the focus adjustment operation completes.

[0069] As described above, according to the present embodiment, focus adjustment can be performed with high accuracy even in an image capturing apparatus having a lens that includes a reflective optical system.

Other Embodiments

[0070] Embodiment(s) of the present invention can also be realized by a computer of a system or apparatus that reads out and executes computer executable instructions (e.g., one or more programs) recorded on a storage medium (which may also be referred to more fully as anon-transitory computer-readable storage medium') to perform the functions of one or more of the above-described embodiment(s) and/or that includes one or more circuits (e.g., application specific integrated circuit (ASIC)) for performing the functions of one or more of the above-described embodiment(s), and by a method performed by the computer of the system or apparatus by, for example, reading out and executing the computer executable instructions from the storage medium to perform the functions of one or more of the above-described embodiment(s) and/or controlling the one or more circuits to perform the functions of one or more of the above-described embodiment(s). The computer may comprise one or more processors (e.g., central processing unit (CPU), micro processing unit (MPU)) and may include a network of separate computers or separate processors to read out and execute the computer executable instructions. The computer executable instructions may be provided to the computer, for example, from a network or the storage medium. The storage medium may include, for example, one or more of a hard disk, a random-access memory (RAM), a read only memory (ROM), a storage of distributed computing systems, an optical disk (such as a compact disc (CD), digital versatile disc (DVD), or Blu-ray Disc (BD)™), a flash memory device, a memory card, and the like.

[0071] While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

What is claimed is:

1. An image capturing apparatus, comprising:

an image sensor configured to capture a subject image; and

at least one processor or circuit configured to function as

a focus detection unit configured to, based on an image signal obtained by photoelectrically converting the subject image in accordance with the image sensor while performing a scan operation that causes a focus lens included in an imaging optical system to move along an optical axis of the imaging optical system, calculate a focus evaluation value indicating a degree of focus of a subject and detect a position of the focus lens at which the focus evaluation value is a maximum,

wherein the focus detection unit, in a case where the imaging optical system includes a reflective optical system in which a part of a light beam is blocked, sets a calculation method of the focus evaluation value or a control method of the focus lens during the scan operation based on information relating to a shape of the reflective optical system.

2. The image capturing apparatus according to claim **1**, wherein the information relating to the shape of the reflective optical system includes information relating to a pupil function of the reflective optical system.

3. The image capturing apparatus according to claim **2**, wherein the information relating to the shape of the reflective optical system includes information relating to an inner diameter and an outer diameter of an opening of a doughnut shape corresponding to the pupil function on an exit pupil plane of the reflective optical system.

4. The image capturing apparatus according to claim **3**, wherein the information relating to the shape of the reflective optical system includes information of F number corresponding to the inner diameter and the outer diameter of the opening of the doughnut shape.

5. The image capturing apparatus according to claim **1**, wherein the information relating to the shape of the reflective optical system includes information relating to an MTF of the reflective optical system.

6. The image capturing apparatus according to claim **1**, wherein the focus detection unit sets a focus detection frequency for calculating the focus evaluation value based on the information relating to the shape of the reflective optical system.

7. The image capturing apparatus according to claim **1**, wherein the focus detection unit calculates the focus evaluation value by performing a coarse scan operation in which one step of moving interval of the focus lens is a first interval and a fine scan operation in which one step of moving interval of the focus lens is smaller than the first interval as the scan operation of the focus lens.

8. The image capturing apparatus according to claim **7**, wherein the focus detection unit more finely calculates the position of the focus lens at which the focus evaluation value is a maximum by the fine scan operation based on a maximum value of the focus evaluation value obtained by the coarse scan operation.

9. The image capturing apparatus according to claim **7**, wherein the focus detection unit sets a focus detection frequency used in a coarse scan operation for a lens that has an opening corresponding to an inner diameter of an opening of a doughnut shape corresponding to a pupil function on an exit pupil plane of the reflective optical system as a focus detection frequency of a coarse scan operation for the imaging optical system and sets a focus detection frequency used in a fine scan operation for a lens that has an opening corresponding to an outer diameter of the opening of the doughnut shape as a focus detection frequency of a fine scan operation for the imaging optical system.

10. The image capturing apparatus according to claim **1**, wherein the focus detection unit sets one step of moving interval of the focus lens in the scan operation based on the information relating to a shape of the reflective optical system.

11. The image capturing apparatus according to claim **1**, wherein the focus detection unit calculates the focus evaluation value by applying a filter corresponding to an MTF characteristic of a lens that has an opening corresponding to an inner diameter of an opening of a doughnut shape corresponding to a pupil function on an exit pupil plane of the reflective optical system.

12. A method of controlling an image capturing apparatus having an image sensor configured to capture a subject image, the method comprising:

based on an image signal obtained by photoelectrically converting the subject image in accordance with the image sensor while performing a scan operation that causes a focus lens included in an imaging optical system to move along an optical axis of the imaging optical system, calculating a focus evaluation value indicating a degree of focus of a subject and detecting a position of the focus lens at which the focus evaluation value is a maximum,

wherein in the detecting, in a case where the imaging optical system includes a reflective optical system in which a part of a light beam is blocked, a calculation method of the focus evaluation value or a control method of the focus lens during the scan operation is set based on information relating to a shape of the reflective optical system.

13. A non-transitory computer readable storage medium storing a program for causing a computer to execute a method of controlling an image capturing apparatus having an image sensor configured to capture a subject image, the method comprising:

based on an image signal obtained by photoelectrically converting the subject image in accordance with the image sensor while performing a scan operation that causes a focus lens included in an imaging optical system to move along an optical axis of the imaging optical system, calculating a focus evaluation value indicating a degree of focus of a subject and detecting a position of the focus lens at which the focus evaluation value is a maximum,

wherein in the detecting, in a case where the imaging optical system includes a reflective optical system in which a part of a light beam is blocked, a calculation method of the focus evaluation value or a control method of the focus lens during the scan operation is set based on information relating to a shape of the reflective optical system.

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